

Article

Building Information Modeling Based Building Sustainability Assessment Framework for Kazakhstan

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Abstract: The use of building information modeling (BIM) for building sustainability assessment (BSA) is a thriving topic within the architecture, engineering, and construction industry. Despite the various research approaches to employing BSA with BIM support, the research is limited to the BIM implications of BSA methods in developing countries. This paper presents how BIM can assist the BSA processes in Kazakhstan, using a previously developed building sustainability assessment framework for Kazakhstan (KBSAF). This framework has 46 assessment indicators grouped into nine assessment categories. The categories and assessment indicators of KBSAF were derived considering the regional variations and country-specific differences in the assessment factors. In this paper, BIM functions for BSA were identified through literature review; their applicability for KBSAF was evaluated by mapping the functions with the assessment indicators of KBSAF and a BIM-based BSA framework (BIM-KBSAF) was proposed. The proposed framework was validated through a three-round Delphi survey. One of the results demonstrates that for KBSAF, BIM can assess 24 out of 46 assessment indicators. The proposed framework could serve as a systematic guide to the application of BIM for BSA. Furthermore, it can facilitate the BSA process and save considerable time and effort.

Keywords: building sustainability; green buildings; building information modeling; assessment indicators; Delphi method; inter-rater agreement; conceptual framework; Kazakhstan



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1. Introduction

1.1. Background

The scientific community has widely studied the relationship between the built environment and environmental problems. According to the International Energy Agency [1], buildings consume 36% of final energy and 12% of fresh water and produce 40% of global solid waste and 40% of greenhouse gas emissions. Additionally, the building sector consumes 51% of global electricity and 9% of global petroleum [2]. Although the majority of these figures are for developed countries, experts believe that the impacts of building and construction on the environment and society are considerably worse in developing than in developed countries [3]. Therefore, there is a demand for efficient solutions for reducing buildings' environmental, economic, and social impacts, particularly in developing countries. Building sustainability assessment systems (BSAS) have emerged in different world regions in response to these concerns. These systems are considered useful instruments for achieving sustainability in buildings [4].

Various BSAS are being used in different countries to evaluate buildings' environmental performance. Some of these systems are Building Research Establishment Environmental Assessment Methodology (BREEAM) from the UK, Leadership in Energy and Environmental Design (LEED) from the USA, the Comprehensive Assessment System for Building Environmental Efficiency (LEED) from Japan, Sustainable Building Tool (SBTool)

from Canada, Building Environmental Assessment Method (BEAM Plus) from Hong Kong and Green Star from Australia. In addition, several other methods have been adapted to local conditions, and numerous studies have investigated their approaches [5–7].

Kazakhstan aims to adopt and utilize such practices and tools which decrease environmental impact, especially for the country's high energy consumption, to maintain the desired indoor environmental comfort in severe continental climatic conditions.

The advancement of Building Information Modeling (BIM) has significantly influenced the architecture, engineering, and construction (AEC) industry over the last two decades. BIM is an effective communication platform commonly used by project teams in building design, construction, monitoring, and facilities management [8]. With the increasing attention paid to the depletion of nonrenewable resources and buildings' environmental impact, BIM tools are employed to predict and monitor construction activities' environmental effects [9,10]. Previous studies have shown that BIM can assist in various sustainable design areas and support the building certification processes [8,11,12]. Both BIM and building sustainability assessment (BSA) concepts are relatively new in Kazakhstan's construction industry. The greening of the building sector in Kazakhstan began in 2013 by adopting the Green Economic Concept policy. As a result, there was a rise in the usage of international BSAs in the construction industry [13]. Currently, BREEAM and LEED are the most popular rating tools within the construction industry in Kazakhstan. In 2014, the Kazakh government announced its plan to establish a national BSAs, and following that, the Kazakhstan Green Building Council (KazGBC) was established. Meanwhile, the BIM application in the construction industry in Kazakhstan was initiated by the Committee for Construction and Housing in 2016. By 2023, the Committee intends to fully implement BIM in all its projects from design through building commissioning phases [14].

This paper reports the last phase of the study project on developing the BIM-based BSAs in Kazakhstan. In contrast, most of the other relevant studies are for international BSAs with BIM applications. As a result of the previous two phases [15,16], a conceptual framework of building sustainability assessment for the commercial buildings in Kazakhstan was developed [15], which was consolidated using multi-criteria decision-making into a sustainability assessment system—KBSAF [16]. The key features of the system are described in Section 2.2.

1.2. Research Goal, Objectives, and Contribution

This research aims to develop a conceptual framework for BIM integration into the multi-criteria decision-making framework for BSA in Kazakhstan. Hence, the research has the following objectives: (RO1) to identify the application of BIM for building sustainability assessment, (RO2) to assess the application of BIM for the assessment indicators of KBSAF, and (RO3) to propose and validate the conceptual framework for the BIM-based building sustainability assessment framework (BIM-KBSAF).

Based on the study objectives, this paper has the following research questions: (RQ1) Which assessment indicators of KBSAF have support from past research on BIM applications for building sustainability? (RQ2) Which assessment indicators of KBSAF have no support from past research on BIM applications for building sustainability? (RQ3) Can those assessment indicators that have not found support from past research for BIM applications be supported with BIM? (RQ4) What, if any, are the assessment indicators that BIM applications cannot support? (RQ5) What potential applications and tools can be used as BIM support for KBSAF assessment indicators? (RQ6) How can the collected information about BIM applications be used to formulate a BIM-based sustainability assessment system framework?

The results of this study may contribute to the existing body of knowledge on BIM and building sustainability assessment by presenting a methodology for BIM integration into the building sustainability assessment framework considering the BIM functions and KBSAF criteria. This integration may allow the project team to test different sustainable design scenarios early, thus saving time, costs, and other project resources.

1.3. Contents of the Paper

This paper is structured as follows: the next section provides a brief resume of BIM and its use in the BSA based on the literature review. Moreover, in the next section, a summary of the multi-criteria decision-making framework developed from the previous two phases of this study for commercial buildings in Kazakhstan is provided. In the third section, an explanation of the research design and methodology is given. The fourth section presents and discusses the findings and results of the study. The fifth section presents the validation survey of the proposed framework, and finally, the last section concludes the research paper.

2. Literature Review for the Research Background

2.1. BIM and Building Sustainability Assessment

Building sustainability has become a noticeable concern in the development of sustainable cities. The decisions made in the early design stages significantly influence the building's environmental impact [17]. Advanced approaches have been introduced to aid designers in managing and making decisions in early design phases. Building Information Modeling (BIM) is one such advancement. BIM is a methodology that allows the storage of project data in digital formats and the management of these data in 3D drawing during the entire building lifecycle [18]. BIM is effective in enhancing the productivity of design and management [19]. BIM incorporates multidisciplinary information into one model, thus providing an opportunity to incorporate environmental performance analyses and sustainability enhancement measures throughout the design stages [8].

Recently, there has been increasing research interest in BIM integration into sustainable assessment, and several research efforts have been initiated. BIM is most commonly used to support LEED [20]. For instance, Azhar et al. [17] demonstrated a conceptual framework showing the relationship between BIM and LEED. The research found that BIM can obtain two prerequisites and 17 credits, equivalent to 38 LEED points. These credits are included in different sections, including the sustainable site, water efficiency, materials and resources, energy and atmosphere, indoor environmental quality, and design innovation categories. A study conducted by Alwan et al. [21] examined the feasible BIM application to facilitate buildings' environmental assessment process. The research demonstrated the results through a case study for LEED assessment within the BIM.

Jalaei and Jrade [22] proposed a methodology integrating BIM with the Canadian green building certification system (LEED-C). The methodology explains the model implementation that automatically calculates the compiled number of LEED certification points and related registration costs for green and certified materials in designing sustainable buildings. This methodology helps designers create and animate sustainable buildings in 3D mode using BIM at the conceptual stage. In addition, the BIM model can be linked to an external database that stores sustainable materials and assembly groups. A real case project illustrated the usefulness and capabilities of the proposed model.

Nguyen et al. [23] presented how extracts from the BIM model support the LEED green building system's information assessment. They proposed a framework representing LEED green building criteria's implementation into a BIM platform to obtain an automated tool for rating a green building design.

Efforts for other sustainability assessment systems have also been made. Wong and Kuan [8] explored the potential of using BIM in the BEAM Plus Sustainability analysis. With a two-stage methodology, the study identified the credits that can be achieved using BIM software and tested the application framework's feasibility through case studies of residential buildings. As a result, the research work selected 26 credits of BEAM, plus that can be achieved with the assistance of BIM, which is: four credits in site aspect, eight credits in the material aspect, six credits in energy use, three credits in water use, four credits in indoor environmental quality and one credit in the innovation category.

Carvalho et al. [18] developed a BIM-based application framework focusing on the Portuguese SBTool-H assessment system. The research assessed the applicability of BIM and demonstrated the theoretical possibility of directly and indirectly assessing 24 out of 25 criteria using BIM.

Solla et al. [24] investigated the feasibility of using BIM for facilitating the Malaysian GBI assessment process (GBI: Green Building Index). The study utilized BIM for GBI assessment purposes during the design and operation stages. They collected the research data through a questionnaire survey among GBI members and identified the BIM capability to operate digital GBI criteria. The authors found a strong influence of BIM tools on GBI assessment. They concluded that knowing the weaknesses and benefits of utilizing BIM would be useful for design teams to avoid problems at the design phase. According to Ghandi and Jupp [25], BIM can support the assessment of 66% of the credits of the office building assessment scheme of the Australian Green Star. Hoseini et al. [26] concluded that BIM could help evaluate 75% of the New Zealand Green Star Certification Tool.

With most previous research efforts to apply BIM for sustainability assessment, a general conclusion is that BIM is still not oriented and has not gained its full potential for sustainable building design [20]. In addition, each method's assessment factors and indicators vary depending on local climate and environmental conditions, cultural and socio-economic aspects, standard practices, and regional diversifications. Therefore, this paper attempts to apply BIM to the newly developed BSAS in Kazakhstan (KBSAF) and develop a conceptual framework representing how BIM can assist a BSA. Furthermore, this study may serve as guidance and aid to designers in addressing sustainability issues during the project commencement phase, thus assisting in designing green buildings.

2.2. Kazakhstan Building Sustainability Assessment Framework

Kazakhstan Building Sustainability Assessment Framework (KBSAF) is a multi-criteria decision-making system for commercial buildings in Kazakhstan [15]. KBSAF was developed for non-residential commercial buildings considering the local variations and regional context in Kazakhstan. It includes the most common categories of internationally recognized tools, namely, BREEAM, LEED, SBTool, and CASBEE, and addresses categories and issues specific to the context of Kazakhstan. These four assessment tools were selected based on the following criteria: all four rating systems are internationally recognized and successfully adopted by many developing countries [15]. Moreover, these tools are famous and utilized worldwide by AEC industries; therefore, using them as references will allow contractors and engineers to better understand the process and their contribution towards achieving sustainability criteria [15]. Table 1 lists 46 assessment indicators of KBSAF distributed over nine assessment categories. The category weights are also indicated as determined in reference [16]. The assessment system's overall score is achieved by the percentage of the credits obtained under each category. The assessment framework consists of the following five certification levels: A (80–100%)—completely sustainable building; B (60–79%), C (50–59%), D (40–49%)—certified building; and E (0–39%)—not a sustainable building [16].

This study proposes a framework that illustrates how BIM can assist sustainability assessment for Kazakhstan's commercial buildings using KBSAF for evaluation. For this purpose, this paper investigates and demonstrates the validity of the BSA factors of KBSAF for BIM applications.

Table 1. List of KBSAF assessment categories, indicators, and category weights (adapted from [15,16]).

| | |
|---|--|
| Construction site Selection and Infrastructure Category (14.4%) CSI1: Land use CSI2: Low-impact construction CSI3: Access to social, domestic, and socio-economic facilities CSI4: Access to public and ecological transport CSI5: Greenspace CSI6: Landscape irrigation CSI7: Visual comfort | Water Efficiency Category (10.7%) WE1: Building water conservation WE2: Application of innovative water-efficient equipment WE3: Leak detection WE4: Water-efficient landscaping WE5: Water recycling and reuse |
| Building Architectural and Planning Solutions Quality Category (16.5%) BAS1: Building architectural appearance quality BAS2: Building form and orientation BAS3: Greening the building BAS4: Useful floor space BAS5: Parking capacity BAS6: Space planning solutions BAS7: Safety and inclusiveness of opportunities | Energy Efficiency Category (12.6%) EE1: Building commissioning EE2: Renewable energy sources use EE3: Greenhouse gases emission EE4: Energy-efficient heating and cooling EE5: Energy-efficient equipment EE6: Energy saving—Reduction of electricity consumption EE7: Energy saving—Natural gas efficiency |
| Indoor Environmental Quality Category (19.0%) IEQ1: Thermal comfort IEQ2: Daylighting IEQ3: Insolation level IEQ4: Acoustic comfort IEQ5: Noise protection IEQ6: Air pollution monitoring IEQ7: Natural ventilation | Green Building Materials Category (5.9%) GBM1: Local/regional building materials GBM2: Recycled materials GBM3: Secondary use of recycled materials |
| Waste Category (9.1%) WST1: Construction waste management WST2: Building operation and disposal impact | Economy Category (7.2%) ECON1: Building total lifecycle costs ECON2: Annual operating costs ECON3: Affordability Management Category (4.6%) MAN1: Environmental management certificate MAN2: Green building Accredited expert MAN3: Designer’s green building experience MAN4: Contractor’s green building experience MAN5: Education and awareness |

3. Research Design and Methodology

KBSAF comprises nine assessment categories, 46 assessment indicators (Table 1), and 145 sub-indicators or parameters. The sub-indicators are not shown in this paper due to space limitations. These sub-indicators can be consulted from Akhanova et al. [15]. In this paper, the analysis is based on examining KBSAF assessment indicators relating to the previous works by other researchers in the domain. The mapping links of assessment indicators to BIM were established using the sub-indicators as data for assessing the indicators.

The flowchart of the research methodology is presented in Figure 1. The research objectives (RO1–RO3) and research questions (RQ1–RQ6) are also indicated in the methodology flowchart to represent where these sub-goals have been addressed. The methods are divided into components represented by M1, M2a–M2c, and M3 in Figure 1. Firstly, this research identified those assessment indicators supported by BIM tools through comparison with other research work in the literature (M1). The literature review was conducted to select the previous studies on BIM and BSA. The searches were performed based on the set of keywords including but not limited to “BIM,” “Building Information Modeling,” and the title of the assessment indicator in KBSAF; for example, BIM for land use assessment/evaluation. Secondly, BIM’s potential applications were identified for every assessment indicator (M2a). External data needed for BIM were also identified (M2b). Finally, additional BIM tools and software were determined, for example, required for the simulation and analysis processes (M2c). Once the assessment indicators achievable with BIM were identified, the conceptual framework that illustrated the BIM-based BSA (BIM-KBSAF) was proposed (M3).

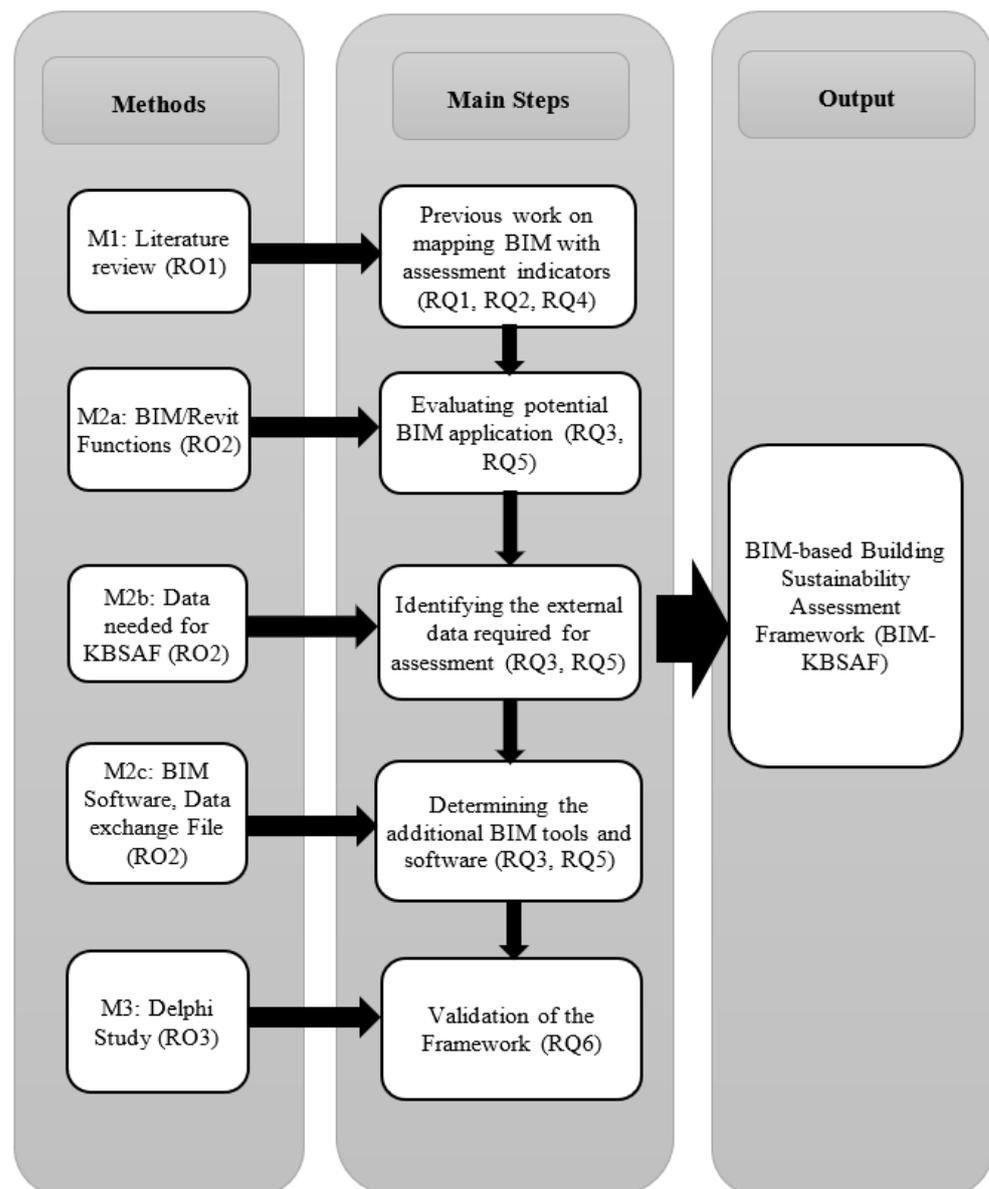


Figure 1. Flowchart of Research Methodology.

In support of the proposed framework, validation was provided by conducting a Delphi study. The Delphi technique was employed to obtain the panelists' general agreement on specific issues systematically. The Delphi study process consisted of selecting the expert panel, designing a questionnaire, scoring rounds of iterations, and analyzing the survey data [27]. The research selected the Delphi technique based on the following characteristics: (a) highly structured process; (b) encourages equal input from all panelists; (c) the expert panel does not need to be large; (d) avoids focusing on a single concept; and (e) formal controlled feedback. Because the Delphi technique focuses on obtaining an expert consensus, the expert panel selection depends on the problem's expertise. As defined by MacCarthy and Atthirawong [27], there are four expertise requirements the Delphi participants should meet: (1) proficiency and experience related to the problem of research; (2) readiness and enthusiasm to cooperate; (3) enough time to take part in the Delphi method; and (4) adequate communication competency. Concerning the size of the panel, the quality of the panel is more important than its number. Because the method does not call the expert panels representative samples for statistical purposes, "a suitable

minimum panel size is seven" [28,29]. Ten experts were invited for this study, and seven experts agreed to participate in the research.

A three-round Delphi survey was conducted to elicit the selected panel's opinions regarding the developed framework components, structure, abstractness, and feasibility. The questionnaire survey was designed based on a five-point Likert scale ranging from (1) for strongly disagree to (5) for strongly agree. Expert responses were analyzed using Cronbach's alpha and interrater agreement (IRA) statistics. The IRA denoted by $a_{wg(1)}$ was employed to analyze and validate each component's expert agreements. Brown and Hauenstein [30] established the IRA in 2005. This study used the IRA measure since it is independent of the sample size and scale of data. The following coding for the IRA analysis was derived by Lebreton and Senter [31] and used in this study: "0.00–0.30 lack of agreement", "0.31–0.50 weak agreement", "0.51–0.70 moderate agreement", "0.71–0.90 strong agreement," and "0.91–1.00 very strong agreement". The IRA equation (Equation (1)) was used to analyze and validate each question's agreement. The IRA cannot measure the agreement at boundary points 1 and 5 on a five-point Likert scale. Therefore, Equations (2) and (3) depict the mean upper and lower limits for the IRA computation.

$$a_{wg(1)} = 1 - \frac{(2 \times SD^2)}{(A + B)M - M^2 - (A \times B) \frac{n}{n-1}} \quad (1)$$

$$M_{upper} = \frac{A(n-1) + B}{n} \quad (2)$$

$$M_{lower} = \frac{B(n-1) + A}{n} \quad (3)$$

where SD —standard deviation, A —maximum value (5), B —minimum value (1), M —mean value of the question, and n —sample size (i.e., 7 in this research).

In the third round of Delphi, 75% was taken as a minimum percentage of consensus on any specific item, according to Nordin et al. [32].

4. Results and Discussions

4.1. Mapping of Assessment Indicators with BIM

The mapping analysis of KBSAF with previous works on BIM is presented in Table 2, which shows for each assessment category the list of assessment indicators that can be assessed with BIM or not. For those indicators which can be assessed, BIM tools, additional software, and data exchange requirement, if any, are also shown. Various BSA methods differ depending on their region of origin, which entails differences in the assessment items from one system to another. Some studies have found that indicators such as acoustic comfort, noise protection, application of innovative water-efficient equipment, water-efficient landscaping, and water recycling and reuse cannot be assessed using BIM [8]. Meanwhile, some other research works have found that additional simulation and analysis can be achieved using BIM to achieve the credit for these assessment indicators [17,18,33,34]. For example, evaluating the insolation level (IEQ3) has not been assessed in other studies; however, Salimzadeh et al. [35] demonstrated that this assessment item could be analyzed using BIM simulation tools. Therefore, in Table 2, some items have been identified with the '*' sign as achievable with BIM. The results of the mapping analysis are described concerning each assessment category.

Table 2. Mapping of KBSAF assessment indicators to BIM.

| Assessment Indicators | Achievable with BIM? | BIM Tools | Additional Software | Data Exchange | Reference |
|---|----------------------|-----------|---|-----------------------|-----------|
| <i>Assessment Category 1: Construction site selection and infrastructure (CSI)</i> | | | | | |
| CSI1: Land use | not linked | | | | |
| CSI2: Low impact site construction | not linked | | | | |
| CSI3: Access to social, domestic, and socio-economic facilities | yes | Revit | | Revit API | [18] |
| CSI4: Access to public and ecological transport | yes | Revit | Geographic Information Systems (GIS), Google Maps | Revit API | [18] |
| CSI5: Greenspace | yes | Revit | GBS | | [18] |
| CSI6: Landscape irrigation | not linked | | | | |
| CSI7: Visual comfort | not linked | | | | - |
| <i>Assessment Category 2: Building architectural and planning solutions quality (BAS)</i> | | | | | |
| BAS1: Building architectural appearance quality | not linked | | | | |
| BAS2: Building form and orientation | yes | Revit | GBS, Ecotect | gbXML | [36,37] |
| BAS3: Greening the building | yes | Revit | | gbXML | [36,37] |
| BAS4: Useful floor space | yes | Revit | | | [8,17] |
| BAS5: Parking capacity | no | | | | [8,17] |
| BAS6: Space planning solutions | not linked | Revit | | | |
| BAS7: Safety and inclusiveness of opportunities | no | | | | [8] |
| <i>Assessment Category 3: Indoor environmental quality and comfort (IEQ)</i> | | | | | |
| IEQ1: Thermal comfort | yes | Revit | Virtual Environment (VE) | IFC, gbXML, Revit API | [8,17,18] |
| IEQ2: Daylighting | yes | Revit | Virtual Environment (VE), DAYSIM RADIANCE | IFC, gbXML, Revit API | [17,18] |
| IEQ3: Insolation level | not linked * | | | | [34] |
| IEQ4: Acoustic comfort | no | | EASE CYPESOUND RRAE | IFC, gbXML, Revit API | [8,17,18] |
| IEQ5: Noise protection | no * | Revit | SoundPLAN, GIS | .dxf | [8,34] |
| IEQ6: Air pollution monitoring | not linked | | | | - |
| IEQ7: Natural ventilation | yes | Revit | Ecotect, GBS | IFC, gbXML | [8,17] |
| <i>Assessment Category 4: Water efficiency (WE)</i> | | | | | |
| WE1: Building water conservation | yes | | Revit | | [17] |
| WE2: Application of innovative water-efficient equipment | yes | | Virtual Environment (VE) | | [8,17,33] |
| WE3: Leak detection | not linked | | | | |
| WE4: Water-efficient landscaping | no | | Virtual Environment (VE) | | [8,17] |
| WE5: Water recycling and reuse | yes | | Green Building Studio | | [8,18] |

Table 2. Cont.

| <i>Assessment Category 5: Energy efficiency (EE)</i> | | | | | |
|--|------------|-------|--|-----------------------|---------|
| EE1: Building commissioning | no | | | | [17,38] |
| EE2: Renewable energy sources use | no | | | | [17] |
| EE3: Greenhouse gases emission | yes | Revit | IES | IFC, gbXML | [8,39] |
| EE4: Energy-efficient heating and cooling | not linked | | | | |
| EE5: Energy-efficient equipment | no | | | | [8] |
| EE6: Energy-saving—Reduction of electricity consumption | not linked | | | | |
| EE7: Energy-saving—Natural gas efficiency | not linked | | | | |
| <i>Assessment Category 6: Green building materials (GBM)</i> | | | | | |
| GBM1: Local/regional building materials | yes | Revit | | | [8,17] |
| GBM2: Recycled materials | yes | Revit | | | [8,17] |
| GBM3: Secondary use of recycled materials | not linked | | | | |
| <i>Assessment Category 7: Waste (WST)</i> | | | | | |
| WST1: Construction waste management | no | | | | [8,40] |
| WST2: Building operation and disposal impact | no | | | | [41] |
| <i>Assessment Category 8: Economy (ECON)</i> | | | | | |
| ECON1: Building total lifecycle costs | yes | Revit | CostX, Green Building Studio, CYPETHERM REH, DesignBuilder | IFC, gbXML, API | [18,42] |
| ECON2: Annual operating costs | yes | Revit | CostX, Vico Office | IFC, gbXML | [18,42] |
| ECON3: Affordability | not linked | | | | |
| <i>Assessment Category 9: Management (MAN)</i> | | | | | |
| MAN1: Environmental management certificate | not linked | | | | |
| MAN2: Green building Accredited expert | no | | | | [8,17] |
| MAN3: Designer’s green building experience | not linked | | | | |
| MAN4: Contractor’s green building experience | not linked | | | | |
| MAN5: Education and awareness | no | | | | [18] |

* yes: past research assessed with BIM; no: past research could not assess with BIM; not linked: research to assess with BIM was not found.

According to the mapping, three indicators in construction site selection and infrastructure categories, land use (CSI1), low impact site (CSI2), and landscape irrigation (CSI6), have no match in other assessment methods. CSI3—access to social, domestic, and socio-economic facilities and CSI4—access to public and ecological transport factors have been reviewed by Carvalho et al. [18]. According to this study, these assessment factors can be obtained using BIM by neighborhood modeling, GIS, and Google maps. CSI7—visual comfort has not been related to BIM in other studies. This research proposes to use the 3D visualization function of Revit to aid this factor.

BAS1—Building architectural appearance quality has no match in other studies. BAS5—Parking capacity and BAS7—safety and inclusiveness of opportunities have been found to match similar studies by Wong & Kuan and Azhar et al. [8,17], concluding that BIM cannot support these two indicators.

In the IEQ category assessment indicators, air pollution monitoring has not been related to BIM previously. Acoustic comfort needs user input in terms of involving an acoustic expert. Hence, BIM cannot aid these criteria.

BIM cannot support the following assessment indicators in the water efficiency category: leak detection (WE3), water-efficient landscaping (WE4), and water recycling and reuse (WE5). By mapping, Azhar et al. [17] found that WE4 is obtainable using BIM, while the research by [8] Wong and Kuan indicate that BIM cannot help this criterion. Based on the assessment parameter (data needed for KBSAF) that requires the existence of a “rainwater collecting system,” the study concludes that BIM cannot support the evaluation of water-efficient landscaping criteria in KBSAF. Therefore, to evaluate this criterion, the existence of rainwater collecting should be checked by the user. WE5 can be assessed by BIM in Carvalho et al. [18].

As Azhar et al. [17] reported, BIM cannot achieve EE1—building commissioning for sustainability assessment purposes. The research work by Wu and Issa [38] has demonstrated that BIM integration may facilitate the commissioning process. Nevertheless, more research is needed to evaluate how BIM can support assessing building commissioning. Assessment indicators such as EE4—Energy-efficient heating and cooling, EE5—energy-efficient equipment, EE6—energy-saving reduction of electricity consumption, and EE7—energy-saving natural gas efficiency have previously not been connected with BIM. In line with the literature review of BIM function analysis, BIM cannot evaluate EE5—energy-efficient equipment and EE7—energy-saving natural gas efficiency criteria.

BIM has not been related to the GBM3—secondary recycled materials criteria in the green building materials category. BIM can aid in recycled material factors. Therefore, this study proposes that BIM can assist in evaluating this criterion also.

Ge et al. [40] stated that construction waste management could be evaluated using BIM tools. Based on this study, this paper suggests evaluating the WST1 factor using BIM. Building operational and disposal impact (WST2) items have not been found in other research studies. Thus, this research concludes that BIM cannot cover the WST2 factor.

ECON3—affordability and three assessment indicators in the management category have not been linked to BIM before.

Based on the mapping analysis with previous work presented in Table 2, 29 assessment indicators of KBSAF were addressed in the previous research studies. These indicators are represented by ‘yes’ for 17 assessment indicators for which BIM can support their evaluation, e.g., BIM can help collect the required information for assessment, analysis, and calculation. At the same time, BIM cannot aid the other 12 assessment indicators, represented by no under the column for achievable with BIM. The remaining 17 assessment indicators are not addressed (not linked) with BIM in previous works, e.g., these indicators have never been connected with BIM. This exclusion can be explained because each assessment system’s assessment categories and indicators might vary depending on the local variations and conditions. Hence, some factors have never been linked to BIM previously. This study analyzed the BIM functions and potential BIM applications for the KBSAF assessment indicators to proceed further. The results are shown in Table 3 and described concerning each KBSAF assessment category.

Table 3. Evaluating the potential BIM application for KBSAF.

| KBSAF Indicators | Data Needed for KBSAF | Potential BIM Application | Covered by BIM? |
|--|---|--|-----------------|
| <i>Assessment Category 1: Construction site selection and infrastructure (CSI)</i> | | | |
| CSI1: Land use | Land category, construction site location | The evaluation of these criteria uses the Land Code of Kazakhstan. Hence, to assess these criteria, the user must collect the information under the Land Code. | no |
| CSI2: Low impact site construction | Protection and restoration measures, compensatory landscaping | BIM cannot support these criteria. The user must collect the information related to the assessment. | no |

Table 3. Cont.

| | | | |
|---|--|--|--------|
| CSI3: Access to social, domestic, and socio-economic facilities | Total number of basic services | For now, BIM cannot help to assess this criterion. However, the distance between the building and the basic service can be measured if the neighborhood is modeled. | no |
| CSI4: Access to public and ecological transport | Walking distance to public transport, availability of bicycle parking, availability of special electric vehicle parking spaces | BIM cannot support the assessment of this criterion. The user must collect information related to bicycle parking and special electric vehicles. | no |
| CSI5: Greenspace | The ratio of the green area to the total area of the construction site, vertical gardening | For assessing this criterion, sub-regions of the top surface with the property "greenspace" were created to obtain the model's green area ratio. | yes |
| CSI6: Landscape irrigation | Type of equipment for land irrigation | BIM cannot aid this criterion. The user must collect the data. | no |
| CSI7: Visual comfort | Lack of monotonous landscape, facades, roofs, windows, and interior | BIM only can aid this criterion through the 3D visualization function. It is recommended that this criterion is reevaluated after the construction is completed. | yes |
| <i>Assessment Category 2: Building architectural and planning solutions quality (BAS)</i> | | | |
| BAS1: Building architectural appearance quality | Building functional purposes, aesthetic preferences | To assess this criterion, the user must collect the related data from the Building Code. | no |
| BAS2: Building form and orientation | Values of thermal efficiency | BIM can aid this criterion through integration with GBS software. Revit Model is exported to GBS software. Different building orientations are adopted, and their impacts are investigated and assessed | yes |
| BAS3: Greening the building | The ratio of green roof in the total roof area | This data can be calculated using BIM. | yes |
| BAS4: Useful floor space | Total specific floor area | BIM can aid in calculating the useful floor space from the BIM model. | yes |
| BAS5: Parking capacity | Number of employees per passenger car | This data should be gathered manually by the user. | no |
| BAS6: Space planning solutions | Building height | BIM can aid in calculating building height from the BIM model. | yes |
| BAS7: Safety and inclusiveness of opportunities | Pedestrian paths, access ramps, traffic speed limit measures | BIM cannot support the evaluation of this criterion. The user processes the information collection. | no |
| <i>Assessment Category 3: Indoor Environmental quality and comfort (IEQ)</i> | | | |
| IEQ1: Thermal comfort | HVAC zoning; temperature regulation | HVAC zoning is obtained from Revit. GBS can perform an energy performance simulation to evaluate the indoor operational temperature. | partly |
| IEQ2: Daylighting | Natural lighting coefficient; artificial lighting | BIM can aid this criterion by daylighting simulation analysis. However, the user should collect information regarding the natural and artificial lighting requirements established by the Kazakhstan Construction Norm SNIP to determine the lighting coefficient's value. | partly |

Table 3. Cont.

| | | | |
|--|--|--|--------|
| IEQ3: Insolation level | Insolation level | BIM can assist in evaluating this criterion by solar radiation simulation. Insolation is measured in a Revit building model. The level of insolation is the ratio of the specified value to the measured insolation. | yes |
| IEQ4: Acoustic comfort | Acoustic expert involvement | The user should process this criterion's assessment under the Construction Norm of Kazakhstan MSN 2.04-03-2005 Noise Protection to perform acoustic measurements. | no |
| IEQ5: Noise protection | Maximum noise level | The maximum noise level can be calculated using BIM. The model is imported into SoundPLAN. Noise source information is entered, and the noise levels are calculated and compared to the maximum noise level. | yes |
| IEQ6: Air pollution monitoring | Air quality evaluation; concentration of VOC; air exchange | BIM can aid in evaluating the air exchange rate in these criteria. The airflow rate can be obtained from Revit by space scheduling function. | partly |
| IEQ7: Natural ventilation | Passive cooling | Floor and open areas are used to calculate the airflow during nighttime. | partly |
| <i>Assessment Category 4: Water efficiency (WE)</i> | | | |
| WE1: Building water conservation | Reduction of specific water consumption per person/year concerning the standard water consumption | BIM can aid this criterion. Green Building Water Usage Estimator can be used to calculate the building water consumption. Related information should be input externally. | yes |
| WE2: Application of innovative water-efficient equipment | Type of equipment | The water usage estimator function of GBS can aid in calculating the number of water-efficient fixtures. This information can be used to assess the criteria for the share of water-efficient equipment. | yes |
| WE3: Leak detection | Type of leak detection system | BIM cannot aid in assessing this criterion. The information should be collected and input manually by the user | no |
| WE4: Water-efficient landscaping | Rainwater collecting system | BIM is not able to evaluate this criterion. The existence of a rainwater collecting system must be checked manually and input by the user. | no |
| WE5: Water recycling and reuse | A system for collecting, cleaning, and reusing rainwater and/or grey waters for sanitary needs, such as using water for flushing toilets and urinals | BIM cannot evaluate this indicator. For assessing these criteria, the information about greywater and rainwater reuse must be collected and processed by the user. | no |
| <i>Assessment Category 5: Energy efficiency (EE)</i> | | | |
| EE1: Building commissioning | Building commissioning compliance | BIM cannot aid this indicator. The user must assess this criterion manually. | no |

Table 3. Cont.

| | | | |
|--|---|---|--------|
| EE2: Renewable energy sources use | Renewable energy share | In some BIM tools, the share of energy produced by local renewable sources can be estimated. GBS can aid in calculating the cumulative energy generated by the solar PVs and wind turbines | partly |
| EE3: Greenhouse gases emission | The building uses passive design measures to reduce the overall CO ₂ emissions by at least 5%. | For assessing these criteria, a CO ₂ emission reduction simulation can be run and calculated. GBS can be used to run the simulation analysis and calculate the CO ₂ emissions. | partly |
| | The building is provided with CO ₂ sensors | The user must collect data on the installation of CO ₂ sensors manually. | |
| EE4: Energy-efficient heating and cooling | Specific heat consumption reduction | BIM tools can aid in conducting energy performance simulations to assess the criterion. The annual and monthly data for the electricity and fuel usage can be obtained from the files 'space heating' and 'space cooling' in GBS. The user must collect and input the data for heat consumption and local climatic files to process it. | yes |
| EE5: Energy-efficient equipment | Energy efficiency class of equipment | This information must be collected and processed by the user. | no |
| EE6: Energy saving—reduction of electricity consumption | Specific electricity consumption | For obtaining these criteria, annual or monthly electricity consumption can be obtained from the GBS sheet and calculated. | yes |
| EE7: Energy-saving—Natural gas efficiency | Share of natural gas heating system in the building | BIM cannot support the evaluation of this criterion. The user processes the information collection. | no |
| <i>Assessment Category 6: Green building materials (GBM)</i> | | | |
| GBM1: Local/regional building materials | The ratio of local building materials | BIM can assist these criteria through the quantity schedule function. The ratio of local building materials can be distinguished in the BIM model and exported to an Excel spreadsheet for further calculation. The creation of a local building materials database is recommended. | yes |
| GBM2: Recycled materials | the ratio of recycled materials | This criterion is assessed similarly to the previous one. | yes |
| GBM3: Secondary use of recycled materials | The ratio of secondary used materials | This criterion is assessed similarly to the previous one. | yes |
| <i>Assessment Category 7: Waste (WST)</i> | | | |
| WST1: Construction waste management | Construction waste management program | The user must gather information regarding the developed construction waste management program. | yes |
| | Quantity of waste reused | The amount of reused waste can be calculated using the BIM tool. The quantity take-off function can be used for waste identification and calculation of reused and recycled waste. | |
| WST2: Building operation and disposal impact | Machine and mechanisms on eco-fuel | The user must collect this information. | no |

Table 3. Cont.

| <i>Assessment Category 8: Economy (ECON)</i> | | | |
|--|---|--|-----|
| ECON1: Building total lifecycle costs | Total building cost | It is possible to estimate the total building cost using BIM. For evaluating these criteria, the user identifies the ratio of traditional building total cost and the BIM model total cost by collecting the necessary data. | yes |
| ECON2: Annual operating costs | Energy, water, maintenance, and repair cost | Annual building water and energy consumption are obtained from the BIM model. The user collects the energy, waste, and water costs. | yes |
| ECON3: Affordability | Rental affordability | BIM cannot support the evaluation of this criterion. Users must process the assessment. | no |
| <i>Assessment Category 9: Management (MAN)</i> | | | |
| MAN1: Environmental management certificate | Presence of certificate | BIM cannot aid this criterion. The user processes the information collection. | no |
| MAN2: Green building Accredited expert | Involvement of Accredited Expert | BIM cannot aid this criterion. The user processes the information collection. | no |
| MAN3: Designer's green building experience | Number of green projects | BIM cannot aid this criterion. The user processes the information collection. | no |
| MAN4: Contractor's green building experience | Number of green projects | BIM cannot aid this criterion. The user processes the information collection. | no |
| MAN5: Education and awareness | Availability of green building user guide/manual, educate and involve the public through case studies | BIM cannot aid this criterion. Thus, the user must manually input the related data for assessment. | no |

4.2. Evaluating Potential BIM Applications

4.2.1. Construction SITE Selection and Infrastructure (CSI) Category

According to the results, BIM can fully aid two assessment indicators in the construction site selection and infrastructure category: CSI5—Greenspace and CSI7—Visual comfort. The ratio of green area to the total construction area should be identified to assess CSI5 criteria. For this purpose, the property 'greenspace' is created in Revit, and the greenspace area is defined [18]. Visual comfort is defined by the lack of monotonous landscape, roofs, windows, and exterior. In the evaluation of this indicator, a 3D visualization function is used. Since BIM allows realistic visualizations in 3D views, the research selected this function of Revit. This function makes it possible to visualize the building in 3D and preliminarily evaluate its appearance. However, it is recommended that reassessment should be performed after the building is constructed. The rest of this category's indicators require manual data collection; hence, BIM cannot assess these indicators. These are Land use (CSI1), Low impact site construction (CSI2), Access to social, domestic, and socio-economic facilities (CSI3), Access to public and ecological transport (CSI4), and Landscape irrigation (CSI6).

4.2.2. Building Architectural Solutions and Quality (BAS) Category

In this, four assessment items can be evaluated with BIM support. The Revit Model can assess assessment indicators, BAS3—Greening building, BAS4—Useful floor space, and BAS6—Space planning solutions. The parameters necessary for assessment can be obtained from the Revit Model. The BAS2-Building form and orientation assessment indicators can be evaluated by integrating Green Building Studio (GBS) software. Different building orientations are adopted, and their impacts are investigated and assessed [37]. The

authors came to this conclusion based on the work performed by Abanda and Bayers [37] that demonstrated the impact of building orientation on its energy efficiency. Hence, this methodology is applied to the proposed framework. Overall, four assessment indicators can be fully evaluated using BIM in this category. In contrast, BAS1—Building architectural appearance, BAS5—Parking capacity, and BAS7—Safety and inclusiveness of opportunities indicators cannot be supported by BIM for assessment purposes.

4.2.3. Indoor Environmental Quality and Comfort (IEQ) Category

Six assessment criteria can be assessed through the BIM assistance in the indoor environmental quality and comfort category. Thermal comfort HVAC zoning is performed in BIM to evaluate IEQ1 partly since the temperature regulation should be carried out manually. BIM can aid in the full evaluation of IEQ2—Daylighting by simulation analysis. However, user interference is required to collect the information regarding the natural and artificial lighting requirements established by the Kazakhstan Construction Norm SNIP to determine the lighting coefficient's value. Finally, the IEQ3—Insolation level can be evaluated using a similar process proposed by Salimzadeh et al. [35].

The model is imported into SoundPLAN to assess IEQ5—Noise protection. Noise source information is entered, and the noise levels are calculated and compared to the maximum allowed noise level [34]. BIM can aid IEQ6—Air pollution monitoring through the Revit space scheduling function. The airflow rate is calculated, and the result is converted from cfm to meter cube per hour. BIM can support the evaluation of IEQ7—Natural ventilation only by providing information regarding the floor and exterior opening areas. All other information must be collected and processed by the user. Thus, BIM can fully support the evaluation of IEQ5—Noise protection and partly assess IEQ6—Air pollution monitoring and IEQ7—Natural ventilation. One indicator that cannot be supported with BIM in this category is IEQ4—Acoustic comfort since it requires the involvement of the acoustic expert to measure the acoustic comfort in the building.

4.2.4. Water Efficiency (WE) Category

In the water efficiency category, two assessment indicators can be evaluated using BIM. These are WE1—Building water conservation and WE2—Application of innovative water-efficient equipment. Both assessment indicators can be evaluated by the water usage estimator of Green Building Studio. For WE1, the building water consumption is calculated compared to the standard water consumption to obtain how much water use reduction is achieved, while for WE2, the number of water-efficient fixtures is estimated to obtain the share of water-efficient equipment [33]. Both indicators can be fully evaluated. The rest of the indicators cannot be evaluated using BIM, including WE3—Leak detection, W4—Water-efficient landscaping, and WE5—Water recycling and reuse.

4.2.5. Energy Efficiency (EE) Category

BIM can assess four items in the energy efficiency category. First, BIM can partially evaluate EE2—Renewable energy sources. In this regard, GBS can be used to calculate the cumulative energy generated by solar PVs and wind turbines. However, due to the software's limited capabilities, renewable energy shared from only two types of renewable energy sources can be evaluated. This limitation does not significantly affect the framework because it considers the overall share of renewable energy sources for the assessment. Thus, user input is necessary to calculate the energy generated by other types of renewable energy sources. Second, the carbon performance of a building is already seen as a key performance indicator. Carbon dioxide (CO₂) is considered the primary greenhouse gas emitted through human activities [43]. The major human activity that generates CO₂ is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation [43]. "The carbon dioxide equivalent (CO₂-eq) is often regarded as an accounting unit for carbon emissions [39] because it takes into account the combined contribution of CO₂, CH₄, and NO₂ as greenhouse gases". Therefore, to assess the EE3—Greenhouse gas emission, GBS

can run the simulation analysis and calculate the CO₂ emission expressed in CO₂-eq. Following the Greenhouse Gas (GHG) Protocol [44], the 'Scope 3' of the greenhouse gas emission covers the indirect emissions in the company's value chain. It includes purchased goods and services, employee commuting, waste disposal, sold products, transportation, and distribution.

Further on, BIM can aid EE4—Energy efficient heating and cooling factor using GBS software. To fully evaluate this criterion from the files 'space heating' and 'space cooling,' the annual and monthly data for the electricity and fuel usage can be obtained. To assess EE6—Energy-saving—Reducing electricity consumption, annual or monthly electricity consumption can be obtained from the GBS sheet and calculated. EE1—Building commissioning, EE5—Energy-efficient equipment, and EE7—BIM cannot cover Energy-saving—Natural gas efficiency factors.

4.2.6. Green Building Materials (GBM) and Waste (WST) Categories

All three assessment indicators of the green building materials category can be fully evaluated using the quantity schedule function of Revit [18].

For WST1—Construction waste management, the quantity take-off function can identify the waste and calculate reused and recycled waste [40]. In this context, reused and recycled waste means the reused and recycled waste the current building uses. This indicator is identified by the ratio of reused and recycled waste to the total generated waste, expressed in percent. BIM cannot cover WST2—Building operations and disposal impact.

4.2.7. Economy (ECON) and Management (MAN) Categories

BIM can fully support two assessment indicators of the economy category. ECON1—Total building costs can be estimated in BIM. This information is used to identify the ratio of traditional building total cost to green building total cost. To obtain the traditional building price, the user must collect the data manually. For ECON2—Annual operating costs, annual building water, and energy consumption are obtained from the GBS. The user collects the energy and water costs. BIM cannot support the ECON3—Affordability factor in this category.

BIM was not found to cover all five assessment indicators in the management category.

4.3. Overall Assessment

The analysis of KBSAF assessment items yields 24 assessment indicators that can be evaluated using BIM tools, including 18 indicators evaluated fully and six indicators partly. It is important to note that some assessment items achievable in other studies have been considered not achievable in this research and vice versa. This difference is illustrated in Table 4 by comparing the assessment indicators achievable with BIM from Tables 2 and 3. The differences are highlighted in bold font for easy identification.

This difference can be explained by the fact that the data needed to assess some sub-indicators of the KBSAF are different from other systems due to the difference in Kazakhstani and other countries' circumstances. These main points that differentiate circumstances from other countries include the data themselves depending on climatic conditions and specific requirements following local building codes, e.g., specific heat, electricity and water consumption, natural and artificial lighting coefficients. Besides, some other issues specific to the Kazakhstani context, such as architectural appearance, maximum noise level factor, and sub-indicators in economy and management categories different from other BSAS. Hence, these data have been used to evaluate the potential application of BIM in the proposed framework.

Table 4. Comparison of results of Tables 2 and 3.

| KBSAF Assessment Indicators | Achievable with BIM | |
|--|---------------------|---------------|
| | Previous Studies | This Paper |
| CSI1: Land use | no | no |
| CSI2: Low impact site construction | no | no |
| CSI3: Access to social, domestic, and socio-economic facilities | yes | no |
| CSI4: Access to public and ecological transport | yes | no |
| CSI5: Greenspace | yes | yes |
| CSI6: Landscape irrigation | no | no |
| CSI7: Visual comfort | no | yes |
| BAS1: Building architectural appearance quality | no | no |
| BAS2: Building form and orientation | yes | yes |
| BAS3: Greening the building | yes | yes |
| BAS4: Useful floor space | yes | yes |
| BAS5: Parking capacity | no | no |
| BAS6: Space planning solutions | no | yes |
| BAS7: Safety and inclusiveness of opportunities | no | no |
| IEQ1: Thermal comfort | yes | partly |
| IEQ2: Daylighting | yes | partly |
| IEQ3: Insolation level | no | yes |
| IEQ4: Acoustic comfort | no | no |
| IEQ5: Noise protection | no | yes |
| IEQ6: Air pollution monitoring | no | partly |
| IEQ7: Natural ventilation | yes | partly |
| WE1: Building water conservation | yes | yes |
| WE2: Application of innovative water-efficient equipment | yes | yes |
| WE3: Leak detection | no | no |
| WE4: Water-efficient landscaping | no | no |
| WE5: Water recycling and reuse | yes | no |
| EE1: Building commissioning | no | no |
| EE2: Renewable energy sources use | no | partly |
| EE3: Greenhouse gases emission | yes | partly |
| EE4: Energy-efficient heating and cooling | no | yes |
| EE5: Energy-efficient equipment | no | no |
| EE6: Energy-saving—Reduction of electricity consumption | no | yes |
| EE7: Energy-saving—Natural gas efficiency | no | no |
| GBM1: Local/regional building materials | yes | yes |
| GBM2: Recycled materials | yes | yes |
| GBM3: Secondary use of recycled materials | no | yes |
| WST1: Construction waste management | no | yes |
| WST2: Building operation and disposal impact | no | no |
| ECON1: Building total lifecycle costs | yes | yes |
| ECON2: Annual operating costs | yes | yes |
| ECON3: Affordability | no | no |
| MAN1: Environmental management certificate | no | no |
| MAN2: Green building Accredited expert | no | no |
| MAN3: Designer's green building experience | no | no |
| MAN4: Contractor's green building experience | no | no |
| MAN5: Education and awareness | no | no |

4.4. Conceptual Framework for BIM-Based Building Sustainability Assessment

The proposed framework (BIM-KBSAF) recognizes the BIM capabilities, defines the sequence of processes, identifies the BIM tools, other related software to analyze and assess the criteria, and allows for interoperability among BIM tools. The study used

Autodesk Revit as the main BIM modeling tool due to its predominant use in Kazakhstan's construction industry [45]. Complementarily, tools such as Green Building Studio and DAYSIM are used for sustainability analysis. The BIM tools were identified based on the evaluation needs of the assessment indicator and by studying the capabilities of the BIM tools. The aim is to connect the BIM functions with KBSAF assessment criteria and develop a framework that illustrates the implementation framework for sustainability assessment using Revit functions and other BIM tools.

The proposed framework consists of the following three phases: the BIM Modeling Phase, Building Sustainability Analysis Phase, and Building Sustainability Assessment Phase (Figure 2). In the first phase, the BIM model is created. The model is then integrated with BIM analysis software in the second phase. Finally, the Excel spreadsheet calculates the assessment items in the third phase and generates the building's sustainability score. The details of the elements in each phase of the framework are further discussed in the subsequent sections.

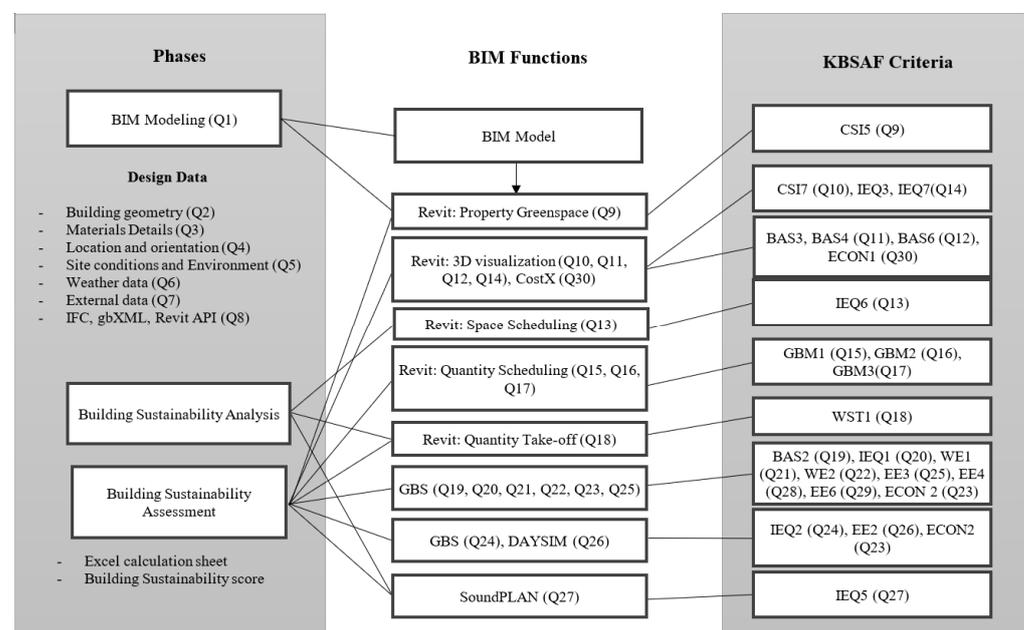


Figure 2. Conceptual Framework for BIM-based Building Sustainability Assessment in Kazakhstan (BIM-KBSAF).

4.4.1. Phase 1—BIM Modeling

This phase includes the data collection for the design and development of the model in Revit. The design data includes project-related information such as building geometry, construction materials, location and orientation, conditions of the site, and weather-related data. Typically, two types of data are used. The first type is the common data related to the whole project information, whereas the second type is specific to the analyzed assessment criteria. For example, the BIM model includes information regarding the site, architectural, mechanical, and plumbing elements.

4.4.2. Phase 2—Building Sustainability Analysis

In this stage, building information is extracted and saved in the IFC or gbXML platforms to enable the model to be exported and used in the sustainability assessment application. Revit API direct link is used to directly evaluate Revit's assessment indicators using the quantity schedule function. Before exporting the model to IFC or gbXML files, "area and volumes" should be set, and project information is given. The inputs are then set, including building type, construction materials, project phase, heating and cooling system type, room zoning, and weather information related to the project's location. The

next step is the creation of rooms or volumes with element properties. Finally, the file is exported to gbXML or IFC and saved. The research identified the following BIM tools for sustainability analysis and assessment: GBS to analyze and assess BAS2, IEQ1, WE1, WE2, EE2, and ECON2 indicators, DAYSIM for IEQ2, and Sound PLAN for IEQ5. There are many other tools developed for sustainability analysis and simulation in the industry. This study has identified these tools as the most widely adopted based on the following criteria: availability and implementation of the tools in local design/construction companies. The following assessment indicators can be directly assessed using Revit Quantity Schedule, Space scheduling, Quantity Takeoff, and Property functions: CSI5, CSI6, BAS3, BAS4, BAS6, IEQ3, IEQ6, IEQ7, GBM1–3, WST1, and ECON1 [18,40].

4.4.3. Phase 3—Building Sustainability Assessment

In this stage, the assessment indicators are calculated. For this purpose, an Excel sheet is prepared and includes the following information: (1) the common design data collected from phase one; (2) information from the Revit model such as floor numbers, floor area, and type of materials; (3) information from sustainability analysis software, that includes the annual energy use, electricity consumption, water use, waste-related data; and (4) the weight of each assessment indicator in KBSAF. In addition, this phase involves the sustainability assessment rating calculation based on the gathered data. Finally, the score of each of the assessment categories and indicators is calculated.

5. Validation of the BIM-Based Building Sustainability Assessment Framework

Validation is a judgment that helps to test whether the framework fits the purpose. When selecting the validation process, the consideration of the validation process circumstances is important. These circumstances are place, cost, and time [46]. According to Inglis [46], there are numerous methods of validation. These approaches include a literature review, input from an expert panel, empirical research, questionnaire survey, and case study research. This research adopted the expert panel input approach and used the Delphi technique. A three-round Delphi study was carried out in September 2020. Table 5 shows the general background of the expert panel.

Table 5. General Background of the Delphi Panel.

| Expert | Position | Experience in BIM | Experience in BSA |
|--------|-------------------------------|--|--|
| 1 | BIM implementation Specialist | Projects partially adopting BIM (3 years) | Understands the concept |
| 2 | General Contractor | BIM adopted in Design and Construction (5 years) | Understands the concept |
| 3 | Architect/Engineer | Have participated in projects fully adopting BIM (5 years) | Have participated in projects that pursued BSA and succeeded |
| 4 | BIM specialist | Projects partially adopting BIM (4 years) | Understands the concept |
| 5 | Architect/Engineer | Projects partially adopting BIM (4 years) | Have participated in projects that pursued BSA and succeeded |
| 6 | Architect/Engineer | Have participated in projects fully adopting BIM (3 years) | Have participated in projects that pursued BSA and succeeded |
| 7 | Sustainability Expert | Projects partially adopting BIM (2 years) | Have participated in projects that pursued BSA and succeeded |

In the first round of the survey, the experts were asked questions about each framework component. The questions are given in Appendix A, and to which component of the framework these questions relate is shown in Figure 2. They were also asked to provide suggestions that might help investigate the potential of using BIM authoring tools to facilitate the BSA process. The first-round results were used to improve the proposed framework further and design the Delphi study's second-round questionnaire. After the

Delphi survey's first round, the panelists were given feedback on the results and asked to rate the items with a low interrater agreement score. Table 6 depicts the results of the first and second-round Delphi technique.

Table 6. Mean, standard deviation, and IRA analysis of first and second rounds of Delphi study.

| Questions | Round 1 | | Round 2 | | IRA | Round 1 | IRA | Round 2 |
|------------------|---------|------|---------|------|------|-----------------|------|-----------------|
| | Mean | SD | Mean | SD | | Agreement Level | | Agreement Level |
| Q1 | 3.86 | 0.38 | 3.86 | 0.38 | 0.92 | Very strong | 0.92 | Very strong |
| Q2 | 4.14 | 1.21 | 4.71 | 0.48 | 0.07 | Lack | 0.62 | Moderate ↑ |
| Q3 | 4.43 | 0.53 | 4.43 | 0.53 | 0.76 | Strong | 0.76 | Strong |
| Q4 | 4.29 | 0.49 | 4.29 | 0.48 | 0.82 | Strong | 0.82 | Strong |
| Q5 | 3.86 | 0.38 | 3.86 | 0.38 | 0.92 | Very strong | 0.92 | Very strong |
| Q6 | 3.00 | 1.00 | 3.14 | 1.06 | 0.56 | Moderate | 0.56 | Moderate |
| Q7 | 3.86 | 0.38 | 3.86 | 0.38 | 0.92 | Very strong | 0.92 | Very strong |
| Q8 | 3.57 | 0.98 | 3.86 | 0.69 | 0.55 | Moderate | 0.55 | Moderate |
| Q9 | 4.14 | 0.69 | 4.14 | 0.69 | 0.7 | Moderate | 0.7 | Moderate |
| Q10 | 3.86 | 0.69 | 4.00 | 0.58 | 0.75 | Strong | 0.75 | Strong |
| Q11 | 4.00 | 0.58 | 4.00 | 0.53 | 0.77 | Strong | 0.77 | Strong |
| Q12 | 3.57 | 0.53 | 3.57 | 0.53 | 0.86 | Strong | 0.86 | Strong |
| Q13 | 3.86 | 1.21 | 4.43 | 0.48 | 0.23 | Lack | 0.75 | Strong ↑ |
| Q14 | 3.71 | 0.49 | 3.71 | 0.79 | 0.88 | Strong | 0.88 | Strong |
| Q15 | 3.43 | 0.79 | 3.57 | 0.76 | 0.72 | Strong | 0.72 | Strong |
| Q16 | 3.29 | 0.95 | 3.71 | 0.75 | 0.6 | Moderate | 0.6 | Moderate |
| Q17 | 3.14 | 1.21 | 3.86 | 0.69 | 0.36 | Weak | 0.75 | Strong ↑ |
| Q18 | 3.14 | 1.07 | 3.86 | 0.69 | 0.5 | Weak | 0.75 | Strong ↑ |
| Q19 | 3.43 | 0.98 | 3.86 | 0.38 | 0.56 | Moderate | 0.56 | Moderate |
| Q20 | 3.43 | 0.79 | 3.86 | 0.57 | 0.72 | Strong | 0.72 | Strong |
| Q21 | 3.57 | 0.98 | 4.00 | 0.57 | 0.55 | Moderate | 0.55 | Moderate |
| Q22 | 3.57 | 0.98 | 3.57 | 0.97 | 0.55 | Moderate | 0.55 | Moderate |
| Q23 | 3.57 | 0.98 | 3.57 | 0.69 | 0.55 | Moderate | 0.55 | Moderate |
| Q24 | 3.43 | 1.27 | 3.86 | 0.69 | 0.27 | Lack | 0.75 | Strong ↑ |
| Q25 | 3.43 | 1.27 | 3.86 | 0.75 | 0.27 | Lack | 0.75 | Strong ↑ |
| Q26 | 3.43 | 1.27 | 3.71 | 0.48 | 0.27 | Lack | 0.72 | Strong ↑ |
| Q27 | 3.29 | 1.11 | 3.71 | 0.48 | 0.45 | Weak | 0.88 | Strong ↑ |
| Q28 | 3.29 | 1.11 | 3.71 | 0.48 | 0.45 | Weak | 0.88 | Strong ↑ |
| Q29 | 3.43 | 1.27 | 3.86 | 0.69 | 0.27 | Lack | 0.75 | Strong ↑ |
| Q30 | 3.43 | 1.27 | 3.86 | 0.69 | 0.27 | Lack | 0.75 | Strong ↑ |
| Cronbach's alpha | 0.95 | | 0.86 | | | | | |

↑ shows the improvement in the agreement level.

The internal consistency of the first and second iteration of Delphi results was verified using Cronbach's alpha. It is a useful test that evaluates the questionnaire [47]. The Cronbach's alpha's value can range between 0 and 1, and a value equal to 0.7 or higher is considered sufficient for further analysis. The alpha value was 0.95 for the first iteration of Delphi and 0.86 for the second round. Thus, both values were greater than 0.7.

After the first round of Delphi, three (3) framework components achieved a 'very strong' agreement. These components were Q1—'BIM modeling phase covers all the elements of Design Data for BIM Model creation,' Q5—'site conditions, and the environment is an essential input in BIM model creation for sustainability evaluation,' and Q7—'external data considered a significant part of the BIM model creation process'. Furthermore, although seven (7) components had no agreement with "lack of agreement" in the first round of the Delphi survey, they improved from 'moderate' to 'strong' agreement after the second round. Moreover, the four (4) expert agreement levels increased after the second iteration, from 'weak' to 'strong,' thereby crediting the Delphi panel's consensus and validating the agreement. In Table 6, these improvements are shown with up-arrows.

The third round of the Delphi method aimed to validate the proposed framework regarding its structure and feasibility. Table 7 shows the results of Delphi round three. In the third round of the Delphi study, a 75% or 3.7 rating score was considered a minimum consensus level for any particular item [32].

Table 7. Results of Delphi round three.

| | Question | Experts | | | | | | | Mean |
|----------|---|---------|---|---|---|---|---|---|------|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| A | The overall structure of the framework | | | | | | | | |
| 1 | Comprehensive approach and includes all major aspects of BIM application in the BSA | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 4.1 |
| 2 | Provides clear guidance on how to apply BIM for BSA | 4 | 4 | 5 | 4 | 4 | 5 | 4 | 4.4 |
| 3 | Facilitates the process of BSA | 4 | 3 | 5 | 4 | 5 | 3 | 5 | 4.1 |
| 4 | The sequence of implementation is easy to follow | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 4.2 |
| B | Feasibility of the Framework | | | | | | | | |
| 5 | The phases are easy to understand and systematic guide to the successful application of BIM for BSA | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 6 | The proposed phases are logical and practical | 4 | 4 | 5 | 4 | 4 | 4 | 5 | 4.1 |
| 7 | Simplify the process even to someone new to BSA | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4.1 |

Expert feedback is an important part of the survey since it enhances the framework by eliminating its shortcomings. The first suggestion by the expert panel was to add the Revit API in the interoperability. Hence, it was added to the framework in the BIM modeling phase. Moreover, several other studies have used the Revit API to integrate BIM with certification systems [18,22]. The second comment was about using some Revit functions and BIM tools in their companies' practices. For instance, a panelist indicated that they did not use SoundPLAN for noise assessment, GBS for renewable energy, or Revit CostX for building total life cost. Nevertheless, the Delphi panelists' overall evaluation feedback indicates that the proposed framework clearly illustrates the phases and BIM functions used to build the sustainability assessment. They also agreed that the implementation sequence is easy to follow, understandable, logical, and practical; thus, the proposed framework could systematically guide applying BIM for BSA.

6. Conclusions

This paper proposed a BIM-based building sustainability assessment framework (BIM-KBSAF) for Kazakhstan. The framework was validated with a three-round Delphi study. The proposed framework provides an overview of the needs for BIM modeling, building sustainability analysis and assessment, and addressing relevant assessment indicators of KBSAF.

Based on the results, it is found that 24 out of a total of 46 assessment indicators of KBSAF can be addressed with BIM. Eighteen of those 24 assessment indicators can be fully addressed, while the other six can be partly addressed. Indoor environmental quality and comfort (IEQ), building architectural and planning solutions quality (BAS), energy efficiency (EE), and green building materials (GBM) were the categories with the highest number of indicators assessable by BIM at six, four, four and three indicators, respectively. Construction site selection and infrastructure (CSI), water efficiency (WE), and economy (ECON) categories each had two indicators assessable by BIM. The waste (WST) category had one indicator assessable by BIM, while the management (MAN) category had no indicators assessable by BIM.

For validation of the proposed framework's accuracy, a Delphi panel study was performed. The results of the Delphi study revealed that the proposed framework clearly illustrates the phases and BIM functions used to build a sustainability assessment. The panel agreed that the implementation sequence is easy to follow, understandable, logical, and practical; thus, the consensus was obtained that the proposed framework could serve as

a systematic guide to applying BIM for BSA. By demonstrating the possibility of integrating BIM with KBSAF assessment indicators, this study's outcome would promote BIM use in the green building assessment and certification in Kazakhstan. The potential applications of the proposed methodology include evaluation of the sustainability level and design support to implement sustainable measures at the early design stages.

However, there are constraints in the usage level of BIM software. Different software tools need to be used to assess more sustainability indicators. Therefore, this research proposed the usage of GBS, SoundPLAN, and DAYSIM for sustainability analysis in addition to the main BIM software: Revit. Nevertheless, many other software and BIM tools in the industry can conduct sustainability analysis. To further validate the methodology's applicability and establish its validity, the developed BIM-based BSA framework in Kazakhstan can be applied to a real case study of an office building.

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Abbreviations

| | |
|-------|---|
| BIM | Building Information Modeling |
| BSA | Building Sustainability Assessment |
| BSAS | Building Sustainability Assessment System |
| KBSAF | Kazakhstan Building Sustainability Assessment Framework |

Appendix A

Validation questions about BIM-KBSAF components:

- Q1. Does the BIM modeling phase cover all elements of Design Data for BIM Model creation?
- Q2. Is building geometry an essential element of Design Data for the BIM Model?
- Q3. Are the details of materials essential for BIM model creation for assessment purposes?
- Q4. Are location and orientation a significant factor for BIM use in a sustainability assessment?
- Q5. Are the site conditions and the environment an essential input in BIM model creation for sustainability evaluation?
- Q6. Should weather data be included?
- Q7. Is External data considered a significant part of the BIM model creation process?
- Q8. gbXML and IFC platforms are sufficient for interoperability for sustainability analysis and assessment in BIM
- Q9. Revit Property greenspace can assist in the assessment of the CSI5—greenspace indicator.
- Q10. Revit 3D visualization can assist in the evaluation of CSI7—Visual comfort.
- Q11. BAS4-Useful floor space can be calculated and assessed by the Revit Model.
- Q12. The Revit Model can evaluate BAS6—space planning quality.
- Q13. Revit Space scheduling can assist in assessing IEQ6—Air quality monitoring.
- Q14. IEQ7-Natural ventilation can be evaluated using Revit.
- Q15. Revit Quantity Schedule can assist in evaluating GBM1—Regional building materials.
- Q16. Revit Quantity Schedule can assist in evaluating GBM2—Recycled materials.
- Q17. Revit Quantity Schedule can assist in evaluating GBM3—Secondary use of recycled materials.

- Q18. Revit Quantity take-off function can help in evaluating WST1—Construction waste management item.
- Q19. BIM integration with GBS can assist in the analysis and assessment of BAS2—Building form and orientation.
- Q20. BIM integration with GBS can assist in the analysis and assessment of IEQ1—Thermal comfort.
- Q21. GBS can aid in the analysis and assessment of WE1—Building water conservation.
- Q22. GBS can aid in the analysis and assessment of WE2—Application of innovative water-efficient equipment.
- Q23. GBS can help evaluate the ECON2—Annual operating costs criteria.
- Q24. GBS can assist in estimating the share of renewable energy produced locally—EE2.
- Q25. GBS can run the simulation analysis and calculate the CO₂ emission using the EE3—Greenhouse gas emission factor.
- Q26. DAYSIM can assist in analyzing and assessing the IEQ2—Daylighting factor.
- Q27. SoundPLAN can assist in the analysis and assessment of IEQ5—Noise Protection.
- Q28. Annual data for ‘space heating’ and ‘space cooling’ for both electricity and fuel usage can be obtained from GBS for EE4—Energy efficient heating and cooling.
- Q29. Annual or monthly electricity consumption can be obtained from the GBS sheet and calculated for EE6- Energy-saving—Reduction of electricity consumption.
- Q30. Revit CostX can be used to assess ECON1—Building total lifecycle cost criteria.

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